A Portion of Energy Transferred to the EAS Electron — Photon Component at $E_0 > 10^{15}$ eV

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Abstract

The estimation of a portion of energy E_{eff}/E_0 transferred to the EAS electron — photon component at $E_0 = 10^{15} \div 10^{19}$ eV has been found by using measurement data of the Cherenkov radiation and charged particles at the Yakutsk array. The results are compared with the models of different energy dissipation into the EAS electron — photon component and with calculations for different primary nuclei. In the energy intervals of $10^{15} \div 10^{16}$ eV and $10^{18} \div 10^{19}$ eV E_{eff}/E_0 is equal to (77 ± 2) and (88 ± 2) %, respectively, that doesn't contradict the mixed composition of primary particles for the first energy interval and the proton composition for the second one.

1. Introduction

Energetic characteristics of a shower such as the energy wasted by particles for the ionizatron of medium and total energy transferred into the electron-photon EAS component are always considered to be important for choosing of the interaction mechanism of a cosmic ray primary particle with nuclei of air atoms and for the estimation of primary particle energy without a definite model. The energy can be estimated only in two cases (without invoking of some notions on the interaction model): 1. when the total flux of Cherenkov light at sea level has been measured; 2. the longitudinal EAS development, a more exactly, the total number of particles in the maximum of shower development has been measured. At present time, only at two EAS arrays such measurements are carried out: at the Yakutsk array (Russia) where the Cherenkov EAS radiation is measured and at the Fly's Eye array (USA) where the ionization nitrogen luminosity is done. For this reason, in Yakutsk the calorimetric method has been suggested and is used for the estimation of energy [1] and at the Fly's Eye array the energy is determined by a number of particles in the shower development maximum [2].

In the present work, a question for the determination of portion of energy transferred to the electromagnetic EAS cascade is studied. The wide energy interval from 10^{15} to 10^{19} eV has been considered. In the method for determination of E_{ei}, and E_{el} the real conditions of the atmosphere, the longitudinal development

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of shower (X_{max}) [3] and the mass composition of primary particles are taken into account.

2. The method for empirical estimation of E_{eph}

To determine the shower primary energy at the Yakutsk EAS array the following expression is used:

$$E_0 = E_{ei} + E_{el} + E_{\mu\nu} + E_d = E_{eph} + E_{\mu\nu} + E_d. \quad (1)$$

The components of E_0 in (1) can be restored with the use of integral EAS characteristics. In the given case we are interested only in the first two summands, E_{ei}, and E_{el}. The energy of ionization losses by electrons in the atmosphere above an observation level is determined according to the formula:

$$E_{ei} = k(x, P_\lambda) \cdot \Phi. \quad (2)$$

Here Φ is a total flux of EAS Cherenkov light; $k(x, P_\lambda)$ is a coupling coefficient (calculated value) taking into account the transparence of the real atmosphere, the character of longitudinal shower development (energy spectrum of secondary particles and its dependence on a shower age) and expressed through the EAS development maximum depth measured at the Yakutsk array [3].

The energy transferred by electrons beyond the observation level has been determined according to the expression:

$$E_{el} = 2,2 \cdot 10^6 \cdot N_s(X_0) \cdot \lambda_{eff}., \quad (3)$$

where N_s is the total number of charged particles at sea level and $\cdot\lambda_{eff}$ is the absorption path of shower particles found by us from the correlation of parameters $N_s - Q(400)$ at different zenith angles. In the analysis the EAS data bank with Cherenkov emission accumulated at the Yakutsk array for the 30 year time period ($1973 \div 2003$) has been used. $\sim 3 \cdot 10^5$ showers in all, have been analyzed.

EAS events have been chosen by the Cherenkov light flux density Q(400) at a distance of 400 m from a core. The Q(400) parameter is proportional to the primary energy [3]

$$E_0 = (9,0 \pm 2,1) \cdot 10^{17} + (1,03 \pm 0,01) \cdot \lg(Q(400)/10^7) \quad (4)$$

Thus, the showers have been practically selected by primary energy E_0. In selecting the transparency of the atmosphere, the determination accuracy of a core and other EAS parameters have been also taken into account. Further by chosen showers, the mean lateral distribution functions (LDF) of the Cherenkov light, charged particles, muons with $E_{th} \geq 1$ GeV and correlations of N_s, N_μ parameters at the fixed Φ have been constructed.

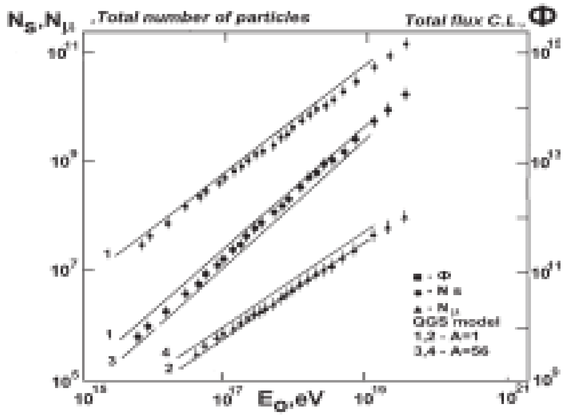

Fig. 1. Mean EAS characteristics measured at the Yakutsk array. (■) — the total Cherenkov light flux Φ; (•) — the total number of charged particles at sea level N_s; (Δ) — the total number of muons with $E_{th} \geq 1$ GeV N_μ.

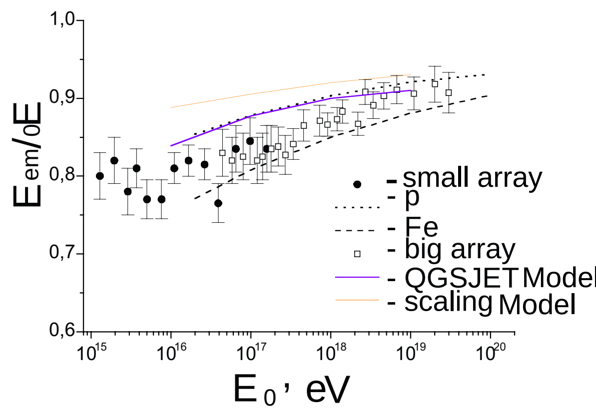

Fig. 2. A portion of the energy transferred to the electromagnetic EAS component by Cherenkov light data at the Yakutsk array.

3. Results

Fig. 1 presents the dependence of the EAS main N_s, N_μ, Φ parameters on the primary energy. By these data, according to (1) and (2), the energetic characteristics of E_{ei}, E_{el} have been determined. The dependence of them on the energy is shown in Fig.2.

4. Discussion

Fig. 2 presents the EAS Yakutsk array experimental data and calculations by the model with the decelerated and moderate dissipation of the energy into the electromagnetic EAS component: quasiscaling models (solid line) and QGSJET (dashed line) [4]. From Fig.2 it is seen both the agreement of experimental data and calculations by QGSJET model (proton) in the region $E_0 \geq 3 \cdot 10^{18}$ eV, and disagreement at $E_0 \geq 3 \cdot 10^{18}$ eV. The scaling model gives a noticeably greater value of E_{eph}/E_0 in relation to the experimental data that is doubtlessly also connected with the break of scaling function in the region of ultra-high energies.

The experimental data in Fig.2 is well approximated by the expression of a form:

$$E_{eph}/E_0 = (0,964 \pm 0,011) - (0,079 \pm 0,005) \cdot E_0^{-(0,147 \pm 0,008)} \qquad (5)$$

The relation (5) is primarily important for the comparison of estimations of E_0 obtained at the Yakutsk and Fly's Eye arrays. The new estimation of $E_{cal.}$ / E_0 parameter for the Fly's Eye array is given in [5].

$$E_{cal.}/E_0 = (0,959 \pm 0,003) - (0,082 \pm 0,003) \cdot E_0^{-(0,147 \pm 0,006)} \qquad (6)$$

From (5) and (6) a good coincidence of both results, calculation and empirical estimation is well seen. The calculations in [5] have been carried out by the QGSJET model in the case of primary proton and iron nucleus. A good agreement of both calculations in the case of the primary proton is observed. The comparison of experimental data with calculations for the proton and iron nucleus indicates to the fact that the mass composition of particles of cosmic radiation in the energy region of $10^{17} \div 10^{19}$ eV and above $3 \cdot 10^{18}$ eV must differ. At $E_0 \geq 3 \cdot 10^{18}$ eV the mass composition is most likely close to the proton one. Therefore, in estimating the EAS energy at the Fly's Eye array it is more reasonably to use the formula (6). At the Yakutsk array the formula (5) obtained empirically is used. A systematic difference between (5) and (6) doesn't exceed 10% that speaks for a coincidence of estimations of E_0 at the Yakutsk and Fly's Eye arrays.

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